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EUI Working Paper ECO No. 90/13

Learning by Doing and Market Structures

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ECONOMICS DEPARTMENT

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Printed in Italy in July 1990
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LEARNING BY DOING AND MARKET STRUCTURES

by

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June 1990

Abstract. The implications of learning-by-doing on the structure, conduct and performance of an industry are analysed. It is studied under which circumstances entry, exit and changes in the degree of concentration may arise in an industry in the presence of learning possibilities when firms are assumed to be non identical. Our findings can be interpreted from the perspective of an analysis of the evolution of such an industry.

I wish to thank Profs. Pierre Dehez, Alan Kirman and Stephen Martin for helpful comments and suggestions on an earlier draft. Responsibility for still remaining errors is only mine.

1. INTRODUCTION

This paper explores the implications of dynamics economies of scale induced by learning-by-doing on the structure of an industry.

Several phenomena determined by learning-by-doing may arise, as far as the dynamics of allocation is concerned. Strong learning possibilities, coupled with vigorous competition among rivals, ensure that "history matters" (Arthur, 1989 ; David, 1987), in the sense that if a given firm enjoys some initial advantage over its rival, it can capitalize on this advantage in such a way that advantage accumulates over time and makes the rival incapable of offering effective competition in the long run. Accumulation of experience can itself be used as a preemptive move on the part of a firm to deter rivals from entering an industry, or, in other circumstances, to make it less and less profitable for rivals to remain in an industry. Putting it in another way, learning-by-doing may be used for the creation of barriers to entry (Scherer, 1980), or to discourage rivals from remaining in the market.

However, much of the literature analysing oligopolistic industries in the presence of learning-by-doing postulates that an industry structure is given and fixed. Moreover, the analysis is usually restricted to symmetric market equilibria (see Fudenberg and Tirole, 1983; Spence, 1981; Stokey, 1986). It is clear that within these models neither entry, exit and changes in the degree of concentration, nor the evolution of market structures can be properly explained. It is the central purpose of this paper to show under which circumstances these features may arise in an industry in the presence of learning possibilities. Unlike the previous authors we suppose that one of the firms possesses a cost advantage; that is, firms are not initially identical.

The basic model is presented in Section 2. In Section 3 we examine the case of a monopoly. It is shown that learning-by-doing involves a form of sunk cost. If the monopolist produces more than the monopoly output because of the future cost savings it will generate, then the monopolist's current profits are lower than they would otherwise be:

the reduction in current profits is the cost of an asset, knowledge, which is sunk. Learning therefore manifests itself as an irreversibility in production possibilities.[1]

In Section 4 we examine the industry behaviour under duopoly. The effects of the threat of entry on the incumbent's behaviour are analysed in Section 4.1. under the assumption that the incumbent firm can learn. In Section 4.2. the role of learning-by-doing in generating a monopoly is investigated. This issue has also been tackled by Dasgupta and Stiglitz (1988). They show that, if the scope of learning is large, an initial cost advantage accumulates over time, so that market share increases for the advantaged firm, possibly leading to a monopoly. They suppose different initial costs but identical rate of learning for the two firms. We study the effects of a different form of asymmetry. In our formulation, only one firm can learn. In particular, because of learning-by-doing, a firm which has an initial cost disadvantage may become the advantaged firm in a subsequent period. Moreover, we analyse the role of discounting, while the previous authors assume a myopic behaviour. We then compare the effects of learning-by-doing in a "socially managed industry" and in a Cournot duopoly and show that competition may result in a "wrong" number of firms, not only in "wrong" outputs.

In Section 4.3. we extend the analysis of the previous section to the case of asymmetric information. We assume that the firm which does not learn does not know the rate of learning of the other firm. The firm which is learning may have an advantage not to convey the information on the rate of learning honestly. The possibility of inducing exit leads to quantities being higher (and prices lower) than would obtain without the possibility of influencing the exit decision. This is the essence of predation. The analysis developed here is related to that of signalling models dealing with limit-pricing theory (Milgrom and Roberts, 1982). However, our analysis is more complicated than in usual

[1]The idea of additional output by a monopolist in early periods to gain an advantage in later periods also appears in Klemperer (1985)'s model of oligopoly with consumer switching costs.

models. In the standard models the starting point is to establish the action the uninformed player would take in the absence of any signalling considerations. In our setting, on the contrary, we have to solve for all equilibrium actions simultaneously, because both firms are in the market at the starting point.

In Section 5 we examine whether learning effects reduce the prospects for profitable collusion. For this purpose, we consider a dynamic game where firms repeatedly compete in quantities over an infinite horizon. The paucity of explicit game-theoretic models of learning is due to the fact that such models are non repeated intertemporal games. In particular, the literature on learning-by-doing assumes that the post-entry game is a finite horizon one. This typically limits the extent to which firms can collude. By focusing on an infinite horizon model where firms are able to collude, we are able to show that, under certain conditions, learning may no longer be used as a preemptive move on the part of a firm, even if it is allowed to enjoy an initial cost advantage over its rival. Section 6 concludes the paper with final remarks.

2. THE ASSUMPTIONS

In this section we present the assumptions which will be used throughout the paper. A single homogeneous commodity can be produced by two firms, $i = 1, 2$. The analysis which follows concerns for the main part two[2] production periods, $t = 0, 1$. Let q_i denote the output produced by firm i. The inverse demand function is given in each period by $p = p(q)$, where p is the price at which the commodity is sold and $q = q_1 + q_2$ is total output. Firms have access to a constant returns-to-scale technology, described by the cost function $c_i(q_i, x_i) = \varphi_i(x_i)q_i$, where $\varphi_i(x_i)$ denotes the unit cost of firm i when the volume of accumulated production is x_i. Learning-by-doing is captured in the fact that unit cost declines as production experience increases. For the major part of the analysis we allow for firm-specific learning-by-doing[3].

We make the following assumptions:

A.1. (i) $p: \mathbb{R}_+ \rightarrow \mathbb{R}_+$ is continuous on $\mathbb{R}_{++}$ and continuously differentiable on the set Q, $Q = \{ q > 0 \mid p(q) > 0 \} \neq \emptyset$

(ii) $p(q) \geq 0$ for all $q > 0$

(iii) p is non increasing everywhere and strictly decreasing on Q

(iν) $\lim_{q \to +\infty} p(q)q = 0$

(ν) $p(q)q$ is strictly concave on Q

For $i = 1, 2$, we have:

A.2. (i) $\varphi_i: \mathbb{R}_+ \rightarrow \mathbb{R}_+$ is continuous on $\mathbb{R}_{++}$

(ii) $\varphi_i(0) = c_o^i \geq 0$

[2]The operative restriction is not "two" periods, but finitely many, that is, our results generalise easily to any finite number of periods.

[3]The analysis easily generalises to the case of incomplete spillovers.

(iii) $\lim_{x_i \to +\infty} \varphi_i(x_i) = \bar{c}_i \geq 0$

($i\nu$) let $H_i = \{ x_i > 0 \mid \varphi_i(x_i) > \bar{c}_i \} \neq \emptyset$. φ_i is non increasing everywhere and strictly decreasing on the set H_i

(ν) φ_i is convex on H_i

A.3. $\varphi_i(0) < \lim_{q \to 0+} p(q)$.

For given x_i, the profit function of firm i is given by $\Pi_i(q_1,q_2 \mid x_i) = p(q_1+q_2)q_i - \varphi_i(x_i)q_i$, i = 1,2. Assumption A.1. characterizes the inverse demand function in the usual way. It describes a negatively sloping demand function on the set Q. By A.1.(ν) and continuity of the profit function, there exists a unique output level which maximizes joint profits.

Assumption A.2. characterizes the learning curve. It implies that for any firm i experience reduces cost, at a decreasing rate, on H_i. Outside H_i unit cost remains constant over time. Assumption A.3. states that it is possible for profits to be positive at every date (although in equilibrium they may or may not be). Given these assumptions, there exists a (pure strategy) Cournot-Nash equilibrium in the quantity game. Assumptions A.1., A.2., A.3. ensure the uniqueness of this equilibrium.

3. INDUSTRY BEHAVIOUR UNDER MONOPOLY AND SURPLUS MAXIMIZATION

Let us consider a monopoly facing no threat of entry. The profit function is defined by:

$$\Pi(q_o,q_1 \mid c_o) = (p(q_o) - c_o)\, q_o + \delta(p(q_1) - \varphi(q_o))\, q_1 \tag{1}$$

where δ is the discount factor, $0 \leq \delta \leq 1$. If there is no learning-by-doing, i.e. $\varphi(q_o) = c_o$, then $q_o = q_1 = q_m(c_o)$, where $q_m(c_o)$ is the solution of the first order condition:

$$p'(q_m(c_o))q_m(c_o) + p(q_m(c_o)) - c_o = 0 \tag{2}$$

If there is learning, i.e. $\varphi' \neq 0$, then the optimal output levels q_o and q_1 are solution of the following first order conditions (because of assumption of strict concavity of the profit function) :

$$p'(q_o)q_o + p(q_o) = c_o + \delta\, \varphi'(q_o)q_1 \tag{3}$$

$$p'(q_1)q_1 + p(q_1) = \varphi(q_o) \tag{4}$$

The following result holds:

Proposition 1. When there is learning, the monopolist overproduces with respect to the case of absence of learning. Moreover, he produces more in the second period than in the first.

Proof. Let $f(q)=p(q)q$. For $0 \leq \delta \leq 1$, $\delta\varphi'(q_o)q_1 < 0$. Then $f'(q_o) < f'(q_m(c_o))$, that is, $q_o > q_m(c_o)$. Since $\varphi(q_o) < c_o = \varphi(0)$ we have $f'(q_1) < f'(q_m(c_o))$, that is, $q_1 > q_m(c_o)$. By convexity of the learning curve, $\varphi(0) - \varphi(q_o) > |\varphi'(q_o)|q_o$, and therefore $\varphi(0) - \varphi(q_o) > |\varphi'(q_o)|q_o\delta$. Suppose that $q_1 < q_o$. Then $\varphi(0) - \varphi(q_o) > |\varphi'(q_o)|q_1\delta$, that is, by (3) and (4) , $f'(q_o) > f'(q_1)$. This implies that $q_o < q_1$, which is a contradiction. Hence $q_1 \geq q_o$.

$\square$

A baseline for efficiency comparison is to consider the output levels that maximize the present discounted value of total surplus. Surplus at each date is measured by the area under the demand curve minus current costs of production. Let $u(q) = \int_0^q p(Q)dQ$. The problem is then to choose q_0^s and q_1^s so as to maximize:

(5) $$u(q_o) - c_o q_o + \delta[u(q_1) - \varphi(q_o)q_1]$$

The necessary condition for optimality are:

(6) $$p(q_o^s) = c_o + \delta\varphi'(q_o^s)q_1^s$$

(7) $$p(q_1^s) = \varphi(q_o^s)$$

Observe that the industry makes losses in present value terms in the first period: as long as there is scope for learning, the industry prices below current marginal cost. By the comparison among the previous expressions (3), (4) and (6), (7) it is easy to show :

Proposition 2. Under surplus maximization, output is larger in the second period than in the first. Moreover, it is larger than the monopolist's at every date.

Proposition 2 gives the usual inefficiency from monopoly: for any given marginal cost, the monopolist underproduces since marginal revenue rather than price is set equal to marginal cost. However, the situation is even worse than that. Because the monopolist produces less at every date, costs fall more slowly. Hence, at any date when learning is still going on, the relevant marginal cost for the monopolist exceeds marginal cost under surplus maximization.

4. INDUSTRY BEHAVIOUR UNDER DUOPOLY

Let us consider now the case of Cournot competition between duopolists. Since we are interested in explaining under what circumstances entry, exit and changes in the degree of concentration may arise in an industry in the presence of learning possibilities we will study the case where firms are not identical. Firms may differ with respect to initial costs, intensity of learning, or both. We will study the implications on market structures of these cases in turn.

4.1. THE CASE OF ENTRY

Let us assume that firm 2 is not in the market at time 0 and has to decide whether to enter or not at time 1, after observing the quantity produced by firm 1, denoted by q_o. If firm 2 does not enter, then it makes zero profits and firm 1 enjoys a monopoly position. If firm 2 does enter, then firms make simultaneous second period choices q_1^1 and q_1^2 as Cournot duopoly solutions. We assume that firm 1 can learn. The second period unit cost is given by $\varphi_1(q_o)$ for firm 1, and by $\varphi_2(0) = c_o^2$ for firm 2.

Given $q_o \geq 0$, (q_1^1, q_1^2) is a Cournot–Nash equilibrium, i.e. q_1^1 maximizes the following expression:

(8) $$(p(q + q_1^2) - \varphi_1(q_o))q \quad \text{s.t. } q \geq 0$$

and q_1^2 maximizes:

(9) $$(p(q_1^1 + q) - c_o^2)q \quad \text{s.t. } q \geq 0$$

We get q_o as a solution of:

(10) $$\max_{q \geq 0} \quad (p(q)q - c_o^1 q) + \delta[p(q_1^1 + q_1^2) - \varphi_1(q)]q_1^1$$

Obviously, firm 2 enters if, given q_o, then $q_1^2 > 0$ at the Cournot-Nash equilibrium. It is clear that if the cost differential is high enough, i.e. if learning is intense enough, then there will be only firm 1 active at the Nash equilibrium.

We now investigate more precisely under what circumstances entry is prevented. Learning, indeed, may itself be an element for the creation of entry barriers (see Scherer, 1980). In general, under complete information, pre-entry price does not influence the entry decision, because what is actually taken into account by the potential entrant is post–entry behaviour. So there is no incentive to practice limit-pricing. But in the presence of learning by doing the pre-entry action affects the post-entry cost conditions: as a result, there is scope for limit-pricing under complete information as well. Whether this is a possibility depends upon whether the scope for learning is large and upon whether firms are far-sighted.

To analyse this question we specialize to the case of linear demand and linear learning, leading to explicit solutions. For simplicity, we consider the case $c_o^1 = c_o^2 = c_o$. Let us assume that $p(q) = \max(0, a - bq)$, and that the second period unit cost for firm 1 is given by $c_1^1 = \max(\bar{c}, c_o - \beta q_o)$, where β, $\beta > 0$, is the intensity of learning, and $a > c_o$. The linear specification meets the conditions previously imposed, so there will be a unique Cournot– Nash equilibrium in the second period.

If entry is allowed, we get from the first order conditions for profit maximization:

(11) $$q_o = \frac{(a-c_o)(3b+\delta\beta)}{2(3b^2-\delta\beta^2)}$$

(12) $$q_1^1 = \frac{(a-c_o)(b+\beta)}{3b^2-\delta\beta^2}$$

(13) $$q_1^2 = \frac{(a-c_o)(2b^2-\delta\beta^2-b\beta)}{2b(3b^2-\delta\beta^2)}$$

where $3b^2 > \delta\beta^2$ and $2b^2 - \delta\beta^2 - b\beta > 0$. The conditions for entry not to take place require that $2b^2 - \delta\beta^2 - b\beta \leq 0$, i.e. $\beta \geq b(-1 + \sqrt{1 + 8\delta})/2\delta$, in which case:

(14) $$q_1^2 = 0$$

(15) $$q_o = \frac{(a-c_o)(b+\delta\beta)}{2b^2}$$

(16) $$q_1^1 = (a-c_o)/b$$

Therefore, entry does not take place if the intensity of learning is sufficiently large. Obviously, if the difference between firms is not only a difference in marginal costs, but the potential entrant has also to incur a sunk cost of entry, then entry deterrence would be possible with slower rates of learning.[4]

Let us consider now the parameter values such that entry takes place. In this framework it is interesting to study the implications of spillovers. When there are spillovers, then learning is not firm-specific and, in particular, accumulation of experience by one firm may affect the rival's costs. To consider the possibility of diffusion of learning between firms in this framework means that if firm 2 enters, then its costs in period 1 become $c_1^2 = \varphi_2(\alpha q_o)$, where α ia a constant, the extent of learning spillovers, $0 \leq \alpha \leq 1$. If

[4]A question arising in this context is the following. Consider the interval $0 < \beta < b(-1+\sqrt{1+8\delta})/2\delta$, in which entry can take place. Is it profitable for firm 1 to adopt a limit-pricing strategy in the first period to deter entry of firm 2? It is possible to show that in this example there does not exist any q_o large enough to prevent entry (i.e. $q_o \geq (a-c_o)/\beta$), which yields larger profits for firm 1 than in the case of allowed entry. That is, in this example firm 1 has no proper action to take in the first period which will deter entry.

$\alpha = 1$, then learning is industrywide and spillovers are complete (as in Arrow (1962) and Stokey(1986)): in this case the duopoly is symmetric. If $\alpha = 0$, then learning is firm-specific. When $\alpha = 0$ learning-by-doing is a public good and is likely to be undersupplied in duopoly. The profit functions for firm 1 and firm 2 are given by the following expressions, respectively:

(17) $$(p(q_o) - c_o^1)q_o + \delta[p(q_1^1 + q_1^2) - \varphi_1(q_o)]q_1^1$$

(18) $$[p(q_1^1 + q_1^2) - \varphi_2(\alpha q_o)]q_1^2$$

It is now a simple matter to confirm:

Proposition 3. Output in the first period decreases, as diffusion increases.

Proof. From the first order conditions on (17) and (18) we get the following expression : $f(q_o(\alpha)) = p'(q_o(\alpha))q_o(\alpha) + p(q_o(\alpha)) = c_o^1 + \varphi_1'(q_o(\alpha))q_1(\alpha)$, and then:

(19) $$[f'(q_o) - \varphi_1''(q_o)q_1\delta]\frac{dq_o}{d\alpha} = \delta\varphi_1(q_o)\frac{dq_1}{d\alpha}$$

Since $\frac{dq_1}{d\alpha} < 0$, we get $\frac{dq_o}{d\alpha} < 0$. □

4.2. THE EMERGENCE OF MONOPOLY[5]

Let us consider now the situation where both firms are in the market at time $t = 0$. The asymmetry between firms is captured by assuming that firms have different initial costs and differential learning . Given $q_o^1, q_o^2 \geq 0$, (q_1^1, q_1^2) ia a Cournot–Nash equilibrium, i.e. q_1^1 maximizes expression (8) and q_1^2 maximizes expression (9) where instead of c_o^2 we put $\varphi_2(q_o^2)$. Assumptions A.1, A.2 and A.3 ensure the existence of a Cournot–Nash equilibrium. Let us define $\Pi^i(q_o^1, q_o^2)$ as the profit attained by i, at a Cournot–Nash equilibrium, as a function of q_o^1 and q_o^2. Then q_o^1 and q_o^2 are such that q_o^1 maximizes:

$$(20) \qquad (p(q+q_o^2) - c_o^1)q + \delta\Pi^1(q, q_o^2) \quad \text{s.t. } q \geq 0$$

and q_o^2 maximizes:

$$(21) \qquad (p(q_o^1 + q) - c_o^2)q + \delta\Pi^2(q_o^1, q) \quad \text{s.t. } q \geq 0$$

Suppose that one of the firms (say firm 2) enjoys an initial cost advantage over its rival. We want to study the evolution of the industry when the firms behave non cooperatively. In order to study the evolution of an industry which is not obvious immediately, we consider the following situation. We suppose that firm 2 has an initial cost advantage over its rival, i.e. $c_o^2 < c_o^1$, but it does not learn, so that $\varphi_2(q_o^2) = c_o^2$. Firm 1, on the contrary, is allowed to learn. Therefore, in our formulation, the firm which has a cost disadvantage at the initial date becomes the advantaged firm in the second period because of learning-by-doing. Obviously, this is only the extreme version of a more general case. The analysis can be generalised to the case where both firms can learn, with

[5]The results in this section have been anticipated in Agliardi (1990)

differential learning.

In this framework an interesting welfare question arises too. From a social point of view society would want to trade-off high cost production "today" for future cost savings, provided that the discount rate were sufficiently low. Under a market system, however, society would want to keep the firm which does not learn around in the second period to limit the ability of the learning firm to extract monopoly rents. Put another way, there is room for "market failures". To study this question we will compare the effects of learning-by-doing in a socially managed industry and in a Cournot duopoly.

To obtain explicit solutions let us assume that the market demand and the learning curve are linear, that is, $p(q) = \max(0, a - bq)$ and $c^1_1 = \max(\bar{c}, c^1_o - \beta q^1_o)$, with $a > c^1_o$.

Cournot competition. The expected profits for the two firms are given by:

$$(a-b(q^1_o + q^2_o) - c^1_o)q^1_o + \delta(a-b(q^1_1 + q^2_1) - c^1_1)q^1_1 \tag{22}$$

$$(a-b(q^1_o + q^2_o) - c^2_o)q^2_o + \delta(a-b(q^1_1 + q^2_1) - c^2_o)q^2_1 \tag{23}$$

Routine calculations yield the following two–firm unique subgame perfect equilibrium:

$$q^2_o = \frac{3b^2(a+c^1_o - 2c^2_o) - \delta\beta(a+c^2_o - 2c^1_o) - 2\delta\beta^2(a-c^2_o)}{b(9b^2 - 4\beta^2\delta)} \tag{24}$$

$$q^1_o = \frac{(a+c^2_o - 2c^1_o)(3b + 2\delta\beta)}{9b^2 - 4\delta\beta^2} \tag{25}$$

$$(26) \qquad q_1^2 = \frac{3b\ (a+c_o^1 - 2c_o^2) - b\beta(a+c_o^2 - 2c_o^1) - 2\delta\beta^2(a-c_o^2)}{b(9b^2 - 4\delta\beta^2)}$$

$$(27) \qquad q_1^1 = \frac{(a+c_o^2 - 2c_o^1)(3b + 2\beta)}{9b^2 - 4\delta\beta^2}$$

Let $\Delta = c_o^1 - c_o^2 > 0$ denote the initial cost difference. In what follows let us suppose that $a - c_o^2 > 2\Delta$. Therefore $a+c_o^2 - 2c_o^1 > 0$ and $a+c_o^1 - 2c_o^2 > 0$. The assumption that $a - c_o^2 > 2\Delta$ implies that $c_o^1 >> c_o^2$ is not the case, i.e. the initial cost advantage of firm 2 is not such as to yield a "drastic" outcome (q_o^1, $q_1^1 \leq 0$). Obviously, we restrict our attention to the parameter values such that c_1^1 is non negative. Let us denote by δ^* the value of δ such that $c_1^1 \geq 0$ for $\delta < \delta^*$, and define:

$$\overline{\delta} = \frac{3b^2(a+c_o^1 - 2c_o^2) - b\beta(a+c_o^2 - 2c_o^1)}{2\beta^2(a-c_o^2)}$$

$$\beta^* = \frac{3b(a+c_o^1 - 2c_o^2)}{a+c_o^2 - 2c_o^1}$$

$$\underline{\beta} = \frac{3b(a+c_o^1 - 2c_o^2)(a+c_o^2) - 9c_o^1(a-c_o^2)}{2(a-2c_o^1 + c_o^2)(2c_o^2 - a)}$$

The central result is the following:

***Proposition* 4.** The industry becomes a monopoly in the second period if:

(i) $\beta \geq \beta^*$, for every δ

(ii) $\underline{\beta} < \beta < \beta^*$, for $\delta > \overline{\delta}$

That is, (i) if the rate of learning is sufficiently large, or (ii) if it is not so large, but each firm cares mostly about future profits.

Proof. From expressions (25) and (27) it follows that q_o^1 , $q_1^1 > 0$ for any value of δ and β belonging to the intervals for which the problem is properly defined. Moreover, from expression (23) there exists $\underline{\delta}$, $\underline{\delta} > 0$, such that $q_o^2 > 0$ for $\delta < \min(\delta^*, \underline{\delta})$. Let us consider the case $\delta < \min(\delta^*, \underline{\delta})$ From expression (26) it follows that $q_1^2 > 0$ only if $\delta < \overline{\delta}$. Notice that $\overline{\delta} > 0$ only if $\beta < \beta^*$. Observe that $\underline{\delta} < \delta^*$ only if $\beta > \underline{\beta}$. Moreover, there exists $\overline{\beta}$, $\overline{\beta} < \underline{\beta}$, such that $\overline{\delta} < \underline{\delta}$ for every $\beta > \overline{\beta}$. Therefore, if $\beta < \underline{\beta}$ then $q_1^2 > 0$ for every $\delta < \min(\delta^*, \underline{\delta})$; if $\underline{\beta} < \beta < \beta^*$ for every δ; if $\underline{\beta} < \beta < \beta^*$ for $\delta > \overline{\delta}$. That is, for these parameter values, the firm which does not experience learning-by-doing becomes the disadvantaged firm in terms of cost differential and drops out in the second period.

□

Remark 1 Under our assumptions the concentration ratio q_t^1 / q_t^2 increases. That is, $q_1^1 / q_1^2 > q_o^1 / q_o^2$, for all values of δ.

Remark 2. Suppose that $(a - c_o^2) < 2\Delta$. Then $q_o^1 , q_1^1 = 0$, for every δ, while $q_o^2 , q_1^2 > 0$ for certain values of the discount factor. Therefore, the initial cost difference also matters.

Socially Managed Industry. Imagine now that the market for the commodity in question is socially managed. Let $u(q) = \int_0^q p(x)dx$. The problem is then to choose q_o^1, q_o^2, q_1^1, q_1^2 so as to maximize total surplus, i. e

$$(28) \qquad (u(q_o^1 + q_o^2) - c_o^1 q_o^1 - c_o^2 q_o^2) + \delta(u(q_1^1 + q_1^2) - c_o^2 q_1^2 - c_1^1 q_1^1)$$

subject to the following constraints:

$$q_o^1 \geq 0\ ;\quad q_o^2 \geq 0\ ;\quad q_1^1 \geq 0\ ;\quad q_1^2 \geq 0$$
$$c_o^1 - \beta q_o^1 \geq \bar{c}$$

Performing the constrained maximization we get:

(29) $$q_o^1 = \frac{c_o^1 - \bar{c}}{\beta}$$

(30) $$q_o^2 = \frac{a - c_o^2}{b} - \frac{c_o^1 - \bar{c}}{\beta}$$

(31) $$q_1^2 = 0$$

(32) $$q_1^1 = \frac{a - \bar{c}}{b}$$

whenever $\delta > \delta'$, $\delta' = (c_o^1 - c_o^2)/\beta$ [6]. Since $0 < \delta < 1$, it is required that $\beta > (c_o^1 - c_o^2)$. Thus the firm which does not learn ceases to produce in the second period. Notice the interesting part of this result: society would "buy" lower cost in the second period by putting up with higher cost production in the first period. For both firms to produce at the initial time we need $\beta > \beta'$, $\beta' = (c_o^1 - \bar{c})b/(a - c_o^2)$.

Remark 3. To compare this result with the one obtained under Cournot competition, let us restrict the attention to the common intervals $\delta' < \delta < \delta^*$ and $\beta' < \beta < \beta''$ (where β'' is

[6]This condition follows from the positivity of the multiplier associated with the constraint $c_o^1 - \beta q_o^1 \geq \bar{c}$, that is, $\lambda = (c_o^2 - c_o^1 + \delta\beta)/\beta > 0$. The multiplier associated with the constraint $q_1^2 \geq 0$, i.e. $\mu = \delta(c_o^2 - \bar{c})$, is positive if $c_o^2 > \bar{c}$.

obtained by imposing the condition $\delta' < \delta^*$). If $\beta < \underline{\beta} < \beta''$, we get that, for every δ belonging to the relevant range, both firms are active at both periods in Cournot duopoly. This result contrasts with the one in a socially managed industry. That is, competition results in a different number of firms, not only in different output levels

4.3. UNCERTAINTY OVER THE RATE OF LEARNING

Let us consider here the model of Section 4.2. with the following specification. We assume that the value of the rate of learning , β, is not known to firm 2, while firm 1 knows it. For simplicity, we suppose that β may assume only two values: β_h and β_l . Let ρ be the probability that firm 2 attaches to β being high (β_h), and $(1-\rho)$ to β being low (β_l), where $0 \leq \rho \leq 1$. We assume that if 2 knows that $\beta = \beta_l$, then continued operation under Cournot equilibrium behaviour would be profitable for it; while if $\beta = \beta_h$, then it would be more convenient to exit. In these circumstances, it will want to learn about the true value of β, and it can attempt to infer this information from observing the quantity produced after the first period.

It is here that informational asymmetries come into play . Firm 1, indeed, could increase its quantity, even if $\beta = \beta_l$, so that firm 2 expects that $\beta = \beta_h$. If firm 2 took this quantity as indicating that it will lose money under continued operation, and left the market, firm 1 would receive higher profits thereafter than if firm 2 had recognized the true value of β and stayed in. If $\beta = \beta_h$, then both firms are better off if 2 exits. Therefore, firm 1 when $\beta = \beta_h$ would want to convey its information about β honestly. Producing the simple Cournot quantity fails to convey the information on β credibly, so long as the gains to inducing exit, when the rate of learning is sufficiently low, are large enough to provide an incentive for mimicry. This means that to signal this information credibly, when $\beta = \beta_h$, firm 1 must increase the quantity so far that, were $\beta = \beta_l$, it would not be worthwhile to generate this quantity to induce exit.

Thus, the possibility of inducing exit leads to quantities being higher (and prices lower) than would obtain in the absence of the possibility of influencing the exit decision. This is the essence of predation.

In the present context, there may be some equilibria where a low–cost type succeeds in distinguishing itself from a high–cost type, and others where it does not. These are the standard separating and pooling equilibria that occur in models of incomplete information. The analysis is more complicated than in the usual models, however. In the standard models the starting point is to establish the action the uninformed player would take in the absence of any signalling considerations (see, e.g. Milgrom and Roberts (1982)). In the present setting, on the contrary, the action that is required for the low–cost type to distinguish himself depends also on the action of the uninformed player, firm 2, which in turn depends on the action of a high–cost type, which in turn depends on the action of firm 2. Thus, we must solve for all three equilibrium actions simultaneously[7].

Here we will focus on separating equilibria[8] In standard signalling models this term means that the informed player's strategy is an invertible function of its private information, so that the value of this information can be inferred from the observation of the player's action. Here, the informed player's first period quantity is an increasing function of β (see expression (25)), and the uninformed player can infer the value of β from observing this quantity. It is a commonplace that if any separating equilibrium exists in a signalling game with a discrete set of types of the signalling agent, then there will be a continuum of such equilibria. Interest has centered on the efficient ones of these, where the "weakest" type of signalling player does not deviate from what would otherwise be optimal behaviour, while the "stronger" types deviate just enough to deter mimicking by "weaker" ones[9].

---

[7]The necessity to solve for all three equilibrium actions simultaneously also arises in the model of predation and merger of Saloner (1987).

[8]By equilibrium we mean sequential equilibrium. Such an equilibrium consists of strategies for each player as well as beliefs for each about the history of play to date and the values of one another's private information. In particular, at each decision point, each player must find that continuing to play its equilibrium strategy maximizes its expected profits, given its beliefs and the hypothesis that the other will play its strategy. This best response condition rules out equilibria supported by threats which would not rationally be carried out. (Tirole (1989)).

[9]In more standard signalling games, this efficient separating equilibrium has been shown to be the only equilibrium meeting various criteria involving more or less intuitively appeailing restrictions on the signal recipient's beliefs after observing messages that ought not to have arisen in equilibrium (Tirole (1989)). Moreover, Kreps (1984) and Cho and

In order to solve for a separating equilibrium, we begin with the last period and work backward. In a separating equilibrium firm 2 will have correctly inferred the value of β, so in equilibrium the profits that accrue in the last period if $\beta = \beta_l$ will be $(a + c_o^1 - \beta_l q_1^l - 2c_o^2)^2/9b$ for firm 2 and $(a + c_o^2 - 2c_o^1 + 2\beta_l q_1^l)^2/9b$ for firm 1, while if $\beta = \beta_h$ they will be 0 for firm 2 and $(a - c_o^1 + \beta_h q_1^h)^2/4b$ for firm 1, under our assumption that in the former case continued operation is expected to be profitable, and so firm 2 will stay in, while in the latter case it will exit. Knowing the second period payoffs, we can now turn to specify the efficient separating equilibrium outcome in the first period. Three conditions plus some side constraints are required. First, the choice of q_2 of firm 2 must maximize its expected profit, given the choices q_1^l and q_1^h of the two types of firm 1. Second, q_1^l must be maximizing when $\beta = \beta_l$, given the exit rule and the second period profits. Third, q_1^h must be a maximizing response to q_2 when $\beta = \beta_h$, given the exit rule, the second period profit function and the condition that, when $\beta = \beta_l$, firm 1 not find that generating the output that corresponds to $\beta = \beta_h$ and thereby inducing exit is strictly more profitable than selecting q_1^l and having firm 2 stay in. In addition, there are the non–negativity constraints on the output and price levels and on the second period costs, and we must have that firm 1 find that selecting q_1^h when $\beta = \beta_h$ and then receiving the monopoly profit is at least as good as selecting any other output level and then being accommodating rather than inducing exit.

The following express the three optimization conditions:

$$q_2 = \frac{(a-c_o^2) - \rho b q_1^h - (1-\rho) b q_1^l}{2b} \tag{33}$$

Kreps (1986) have shown that these criteria follow from the property of strategic stability introduced by Kohlberg and Mertens (1984). These criteria are not easy to apply to the present game, principally because the recipient of the signal takes an action simultaneously with the signalling by the informed player.

$$(34) \qquad q_1^l = \frac{9b(a-c_o^1 - bq_2) + 4\delta\beta_l\,(a+c_o^2 - 2c_o^1)}{18b^2 - 8\delta\beta_l{}^2}$$

q_1^h maximizes $[a-c_o^1 - b(q_1^h + q_2)]q_1^h + \delta(a-c_o^1+\beta_h q_1^h)^2/4b$ subject to

$$(35) \quad (a-c_o^1-b(q_1^l+q_2))q_1^l + \delta(a+c_o^2-2c_o^1+2\beta_l q_1^l)^2/9b \geq (a-c_o^1-b(q_2+q_1^h))q_1^h + \delta(a-c_o^1+\beta_l q_1^h)^2$$

Expressions (33) and (34) are simply the relevant best responses derived from the first order conditions for 2's choice given its beliefs and for 1's choice when $\beta = \beta_l$. The constraint in (35) gives the condition that mimicry be unprofitable. Using the stability arguments of Kohlberg and Mertens (1986) as applied to signalling games by Kreps (1984), we can replace the inequality in (35) by an equality. The idea is the following. Consider the smallest q_1^h for which (35) holds. No rational high-cost firm would produce an amount so large (or larger), regardless of the inference that firm 2 might draw from such an action. Accordingly, a rational firm 2 should conclude that such an output must have been produced by a low-cost type of firm 1. Therefore, to signal its true type, a low-cost firm needs to produce no more than the smallest q_1^h for which (34) holds.

Solving (33) (34) and (35) (with equality) simultaneously is not an easy task, especially because of the numerous non-negativity constraints which are to be satisfied at the same time. However, the various requirements that the parameters must meet are not mutually exclusive: separating equilibrium exists for a range of parameter values. Table 1 gives the values of q_2, q_1^l, q_1^h for various values of ρ and β_l, given β_h. Moreover, we compare these values with the simple Cournot solutions, which would obtain if firm 2 placed probability ρ on $\beta = \beta_h$. Let these values be q_2^c, q_1^{lc}, q_1^{hc}.

We observe that $q_1^h > q_1^{hc}$ and $q_2 < q_2^c$; for some parameter values $q_2 < 0$. Both the price and firm 2's output, when $\beta = \beta_h$, are definitely lower as a result of the expansion of firm 1's quantity. For other parameter values, either no signalling is necessary, non-negativity is violated, or, the costs of preventing mimicry are so great that firm 1 is unwilling to signal its information. In the first case q_2^c, q_1^{lc} and q_1^{hc} constitute an equilibrium. In the other cases, if equilibrium exists, it involves pooling, because any separating equilibrium involves at least as great deviations from q_1^{hc}. By definition, we must have $q_1^h = q_1^l$. With the quantity being the same under both β_h and β_l firm 2 cannot learn and must make its exit decision on its priors.[10]

[10]In addition to the pure-strategy equilibria above, an equilibrium in which a high-cost firm plays a mixed strategy sometimes exists. This equilibrium is a hybrid of the pooling and separating equilibria.

TABLE 1

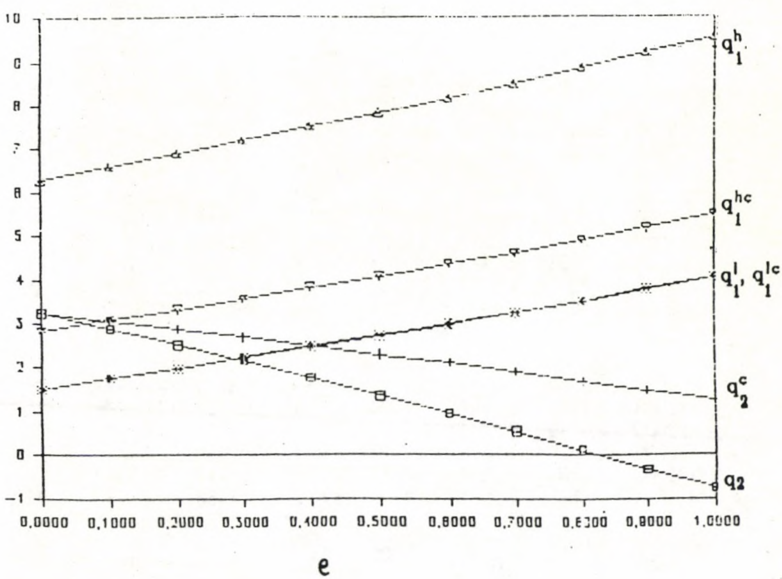
Values of q_2, q_1^l, q_1^h, and q_2^c, q_1^{lc}, q_1^{hc}

for $a = 20$, $c_o^2 = 12$, $c_o^1 = 15$, $\beta_h = 1$.

	ρ	q_2	q_2^c	q_1^l	q_1^h	q_1^{lc}	q_1^{hc}
$\beta_l = 0.2$							
	0.0000	3.5979	3.5979	0.8042	4.3300	0.8042	2.6014
	0.1000	3.3576	3.4450	0.9284	4.5110	0.9266	2.7616
	0.2000	3.1093	3.2861	1.0526	4.6969	1.0529	2.9271
	0.3000	2.8530	3.1211	1.1828	4.8677	1.1834	3.0980
	0.4000	2.5884	2.9497	1.3171	5.0836	1.3181	3.2744
	0.5000	2.3155	2.7716	1.5456	5.2845	1.4571	3.4564
	0.6000	2.0340	2.5868	1.5984	5.4905	1.6004	3.6440
	0.7000	1.7438	2.3947	1.7436	5.7018	1.7481	3.8375
	0.8000	1.4448	2.1952	1.8971	5.9183	1.9003	4.0368
	0.9000	1.1368	1.9882	2.0531	6.1400	2.0571	4.2421
	1.0000	0.8197	1.7732	2.2137	6.3672	2.2185	4.4535
$\beta_l = 0.4$							
	0.0000	3.5008	3.5008	0.9984	4.9467	0.9984	2.6661
	0.1000	3.2262	3.3418	1.1459	5.1621	1.1462	2.8492
	0.2000	2.9424	3.1766	1.2984	5.3831	1.2989	3.0384
	0.3000	2.6492	3.0051	1.4556	5.6098	1.4568	3.2339
	0.4000	2.3465	2.8270	1.6182	5.8421	1.6197	3.4356
	0.5000	2.0343	2.6421	1.7856	6.0801	1.7877	3.6438
	0.6000	1.7124	2.4503	1.9582	6.3237	1.9616	3.8584
	0.7000	1.3808	2.2513	2.1359	6.5731	2.1395	4.0795
	0.8000	1.0394	2.0448	2.3188	6.8281	2.3233	4.3071
	0.9000	0.6881	1.8308	2.5069	7.0888	2.5124	4.5413
	1.0000	0.3268	1.6089	2.7004	7.3552	2.7069	4.7821
$\beta_l = 0.7$							
	0.0000	3.2380	3.2380	1.5240	6.2806	1.5240	2.8413
	0.1000	2.8834	3.0583	1.7499	6.5881	1.7507	3.0777
	0.2000	2.5179	2.8741	1.9826	6.8934	1.9843	3.3214
	0.3000	2.1417	2.6855	2.2219	7.2082	2.2248	3.5722
	0.4000	1.7551	2.4925	2.4677	7.5281	2.4719	3.8299
	0.5000	1.3586	2.2951	2.7198	7.8529	2.7253	4.0943
	0.6000	0.9524	2.0935	2.9780	8.1823	2.9850	4.3651
	0.7000	0.5368	1.8877	3.2422	8.5156	3.2506	4.6421
	0.8000	0.1124	1.6778	3.5121	8.8532	3.5219	4.9251
	0.9000	−0.3206	1.4639	3.7876	9.1941	3.7987	3.2137
	1.0000	−0.7617	1.2461	4.0684	9.5387	4.0807	5.5078

FIGURE 1

Relation between the equilibrium values of q_2, q_1^l, q_1^h
and the Cournot solutions q_2^c, q_1^{lc}, q_1^{hc},
for $\beta_l = 0.7$.



5. IS COLLUSION VIABLE ?

In the previous sections we have shown the implications of learning-by-doing on concentration. In what follows we study whether the presence of learning-by-doing limits the extent to which firms can collude. That is, we want to investigate the following question: does the presence of learning-by-doing and disparities in initial experience between firms inhibit the viability of collusive market–sharing?

One way of analysing the effects of the learning curve on the viability of collusion is to study the effect of learning in the presence of an infinite horizon model, because in this context firms are able to collude. To this purpose we alter the structure of the basic model, by considering a dynamic game where firms repeatedly compete in quantities over an infinite horizon. Notice that this model is a non–repeated intertemporal game because of learning effects.

The single-period game is defined in Section 2. Consider now the infinite horizon model. Each firm has a common discount factor δ, $0 \leq \delta \leq 1$. Let σ_i denote a pure strategy for player i . It is a sequence of functions $\sigma_{i1}, \sigma_{i2}, \dots \sigma_{it}$, one for each period t. Let $q = (q_1, q_2)$. A stream of action profiles $\{q_t\}_{t=0}^{\infty}$ is referred to as an outcome path and is denoted by Q. Any strategy profile $\sigma = (\sigma_1, \sigma_2)$ generates an outcome path $Q(\sigma) = \{q(\sigma)_t\}_{t=0}^{\infty}$. Define by Ω the set of outcome paths.

In this section we specify the asymmetry between the two firms in the following way. We assume for simplicity that the two firms have access to a basic technology of learning which is identical for both firms. The technology of learning satisfies assumption A.2. However, at any point in time, firms may differ with respect to their accumulated experience. More specifically, for any firm i, denote by x_0^i its initial experience, q_t^i its output at date t and x_t^i the accumulated experience at date t. Therefore, $x_t^i = x_0^i + \Sigma_{s=0}^{t-1} q_s^i$.

Let $V^i : \Omega \longrightarrow \mathbb{R}$ define the i–th player's payoff from outcome path $Q = \{q_t\}_{t=0}^{\infty} \in \Omega$:

$$(36) \qquad V^i(Q \mid x_o^i) = \Sigma_{t=0}^{\infty} \delta^t \Pi^i[q_t , x_t^i(x_o^i, \Sigma_{s=0}^{t-1} q_s^i)]$$

where the profit function of firm i at time t is defined by:

$$(37) \qquad \Pi^i[q_t, x_t^i(x_o^i, \Sigma_{s=0}^{t-1} q_s^i)] = [p(q_t^1 + q_t^2) - \varphi(x_o^i + \Sigma_{s=0}^{t-1} q_s^i)]q_t^i$$

Let Q^C be a Cournot–Nash equilibrium path. We say that an outcome path $\tilde{Q}$ is "collusive" if both firms follow that path and no firm gets less profits than it gets following Q^C. Let $\Pi^{i*}(\tilde{Q}|x_o^i) = \max_{q_i} \Pi^i(q^i, \tilde{Q}_{-i}|x_o^i)$, that is, the maximum single period profit that i can obtain if it deviates from the collusive outcome path.

The question arising here is the possibility of providing a setting in which tacit collusion may emerge, supported by credible threats of retaliation for defections from the collusive arrangements. To answer this question we follow the analysis developed by Abreu (1986) . Notice, however, that Abreu considers a repeated game, while our model is a nonrepeated intertemporal one[11].

Abreu introduces a general optimizing approach, emphasizing the central role of "optimal punishments". He argues that the determinant of the limits of collusion is the

[11]The reason why we investigate stick-and-carrot strategies is that these have a natural interpretation in a model with learning-by-doing, and it is precisely the ability to learn that makes these strategies an equilibrium. Segerstrom (1988) introduces repentance strategies as a further development of Abreu's stick-and-carrot strategies. In our framework, it is possible to generalize them to find a subgame equilibrium strategy where the cheater shuts down for a given number of periods, while the other firm produces a best response to that zero output. However, both notions seem not to be "renegotiation-proof" equilibria (Farrell and Maskin (1986)).

severity of punishments with which potential deviants from cooperative behaviour can be credibly threatened. Therefore, in order to derive the highest level of profits that can be sustained as a subgame perfect equilibrium. Abreu inestigates more severe punishments than reversion to a single period Nash equilibrium. That is, whenever any player deviates from the desired equilibrium path, that player is punished by players' switching to the "worst possible equilibrium" for the deviator regardless of the history.

The punishment strategies we use here have the same stick–and–carrot structure that Abreu exploited in the context of repeated games. There are two phases in the constructed equilibrium. In the first phase after defection, the punisher takes the entire market at a loss, while the deviant stays out of the market. Let $\bar{q}_t$ be the relatively high level of output which yields negative profits for the punisher. In the second phase,the punisher is able to produce the "limit output" ($\hat{q}_t$), i. e. the output level such that the other firm cannot make any immediate profit, should it decide to enter and produce. By learning by doing, the punisher makes positive profits in this phase, allowing it to recoup the losses made in the first phase. It is precisely the ability to learn and therefore to lower unit costs that makes the constructed strategies an equilibrium.

Lemma. There exists a lower bound for the discount factor, $\underline{\delta} < 1$, such that it is credible to impose a punishment which yields a zero payoff for $\delta \geq \underline{\delta}$.

Proof Let T be a nonnegative integer. Let $\Pi^i(\bar{q}_t | x_t) < 0$, for t = 0,...T, such that:

(38) $$\Sigma_{t=0}^{T} \delta^t \Pi^i(\bar{q}_t | x_t) < 0$$

Expression (38) shows that in the first phase of the punishment the profits to the punisher are negative. Then define $\hat{q}_t$ as the output sequence that yields the highest profits, subject to the restriction of a zero payoff punishment; because of learning-by-doing the profits in the second phase are positive. Let $\underline{\delta}$ be the discount factor which solves the following expression:

$$(39) \qquad \Sigma_{t=0}^{T} \delta^t \Pi^i(\bar{q}_t \mid x_t) + \delta^{T+1}\Sigma_{t=0}\delta^t \Pi^i(\hat{q}_t \mid x_t)$$

as an equality. For $\delta \geq \underline{\delta}$ the zero-payoff punishment is an optimalpunishment. The only way to allow zero-payoffs punishments is to have negative profits in the first T periods, but not so large that they cannot be recouped by the maximum profits in subsequent periods, subject to the restriction that punishment must yield zero profits in the future. Therefore, the future must be sufficiently important and a lower bound on δ is called for.

The equilibrium can now be erected around this outcome path. Unilateral deviations are not profitable. It is straightforward to verify that the implied pair of strategies yield a subgame perfect equilibrium (Abreu, Theorem 19). □

The following Proposition holds:

Proposition 5. There exists δ^* such that collusion is viable for $\delta > \delta^*$.

Proof. The condition that deters firm i from deviating from the collusive output sequence $\tilde{Q} = \{\tilde{q}_t\}_{t=0}^{\infty}$ is.

$$(40) \qquad \Sigma_{t=0}^{\infty} \delta^t \Pi^i(\tilde{q}_t \mid x_t) \geq \Pi^{i*}(\tilde{Q} \mid x_o^i), \qquad i = 1,2$$

Let $\tilde{\Pi}_t^i = \Pi^i(\tilde{q}_t \mid x_t)$, $\tilde{\Pi}_o^i = \Pi^i(\tilde{q}_t \mid x_o^i)$, $\Pi^{i*} = \Pi^{i*}(\tilde{Q} \mid x_o^i)$, $\Pi^{i*}_{\infty} = \Pi^{i*}(\tilde{Q} \mid \infty)$. Since $\tilde{\Pi}_t^i > \tilde{\Pi}_o^i$ and $\Pi^{i*}_{\infty} > \Pi^{i*}$, then we get as a sufficient condition for (40):

$$(41) \qquad \delta > \delta_i = 1 - (\tilde{\Pi}_o^i / \Pi^{i*}_{\infty}), \quad \delta_i < 1.$$

Take $\delta' = \max_i(\delta'_i)$ and $\delta^* = \max(\delta', \underline{\delta})$. Then for $\delta > \delta^*$ collusion is viable.

□

Proposition 5 gives the conditions to get a collusive outcome. The intuition is clear. Even if firms are asymmetric, in equilibrium the disparity between the firms will vanish in the long run, if firms discount future profit at a low rate. The reason is that with finite output even the disadvantaged firm can reduce its production cost to $\bar{c}$. Then it pays both firms to produce: in particular, a collusive outcome may be profitable for them.

6. FINAL REMARKS

The implications of learning-by-doing on the structure, conduct and performance of an industry are studied. In particular, the central purpose of the paper is to study under which circumstances entry, exit and changes in the degree of concentration may arise in an industry in the presence of learning possibilities. Our results can be interpreted from the perspective of an analysis of the evolution of such an industry.

Closely related to our work are the issues tackled by Brian Arthur and Paul David in their writings on cumulative causation occurring in path-dependent processes [12]. They argue as well that "history matters" when increasing returns to adoption are introduced. If one technology gets ahead by good fortune, it gains an advantage, with the result that the adoption market may "tip" in its favour and may end up dominated by it (Arthur (1989)). Given other circumstances, a different technology might have been favoured early on, and it might have come to dominate the market. Thus, in competition between technologies with increasing returns ordinarily there are multiple equilibria. As to which actual outcome is selected from these multiple candidate outcomes, it is argued that the prevailing outcome turns out to depend on the path which has been initially chosen. An interesting consequence is that the resulting outcome may be inefficient. That is, the market may be locked-in to the "wrong" technology. This circumstance makes room for a central authority intervention.

About policy interventions in the presence of learning effects a final remark is in order. Among our findings, there are the following, which seem to go against the common attitude. First, when learning possibilities are powerful, unless spillovers among firms are perfect, there is a tendency towards the emergence of dominant firms, and thus

[12]More than on learning-by-doing, they stress the role of different sources of increasing returns to adoption, such as learning-by-using effects, network externalities, technological interrelatedness.

concentration. However, it does not follow that a single large firm in an industry must per se be bad (Section 4.2). If learning effects are significant, monopoly is not necessarily the worst form of market structure. Duopoly may be worse for society: the infant phase of an industry may be prolonged. Second, during the learning phase a protected private monopolist may wish to price its product below its current unit production cost (Section 3). However, if an incumbent firm does price its product below production costs it does not follow that it is engaged in predatory pricing. These considerations imply that the common attitude in policy interventions, and especially anti-trust policies, may be questionable in the presence of learning effects.

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